# Healthcare Applications of Mobile Robotics during the COVID-19 Pandemic Response

**Mobile robots can help keep healthcare workers safe during the COVID-19 pandemic by separating them from patients, minimizing the number of in-person interactions required during a course of treatment, and by reducing overall consumption of personal protective equipment.**

**Boston Dynamics has been working with healthcare organizations to model and test the use of mobile robots in the following applications:**

1. **Telepresence and telemedicine**
2. **Remote vital inspection**
3. **Disinfecting hospital rooms**
4. **Internal delivery**

**This document is intended as a resource for roboticists, makers, and healthcare professionals to use in building solutions to help and protect those on the frontlines of the pandemic response. While the work compiled here focuses on Boston Dynamics and its quadruped robot Spot, the findings here can easily be adapted to other robotic platforms, including wheeled and tracked robots.**



## General requirements

1. **Safety**

   **The robot should do no harm. It should be able to be operated safely without risk to patients and healthcare workers. Regular proximity to and contact with people who have not received robot safety training should be expected. Hospital environments are crowded and hectic; the robot should minimize trip and collision hazards. Deployments of mobile robots should be approved by the facility's internal review board.**

2. Sanitization

   Ability to disinfect the robot between patient interactions. Typical disinfection procedures include cleaning with disinfecting wipes or soapy water. Robot cladding, payloads, and other materials should be non-reactive with these cleaning agents. Care should be taken to minimize cleaning agent contact with exposed wiring, crevices, robot joints, electronics, ports, and cameras. Hard to reach areas should be covered.

   Cooling fans and appropriate filtrate should be evaluated to ensure that virus particles are not emitted by the robot during operation.

3. Communications

   Reliable secure communication between the operator and the robot is critical. Additionally, communications should not cause interference with, or deprive bandwidth from, critical hospital systems. Hospitals are challenging comms environments — working closely with hospital IT teams is essential.

4. Privacy

   The robot should not log, record, or store patient information. As with communications, all information management should conform to the hospital's IT, privacy, and data security practices.

# Telepresence / telemedicine

Allow healthcare providers to conduct triage and patient rounds while minimizing their potential exposure to COVID-19 and reducing PPE consumption. Conduct two-way remote interactions. Enable remote or quarantined healthcare workers to support on-the-ground staff.

## Solution requirements

Minimum:

1. Two-way audio from the operator to the robot to enable patient interviews.
2. Two-way video from the operator to the robot for patient interactions and to show that there's a human on the other side of the connection.

Ideal:

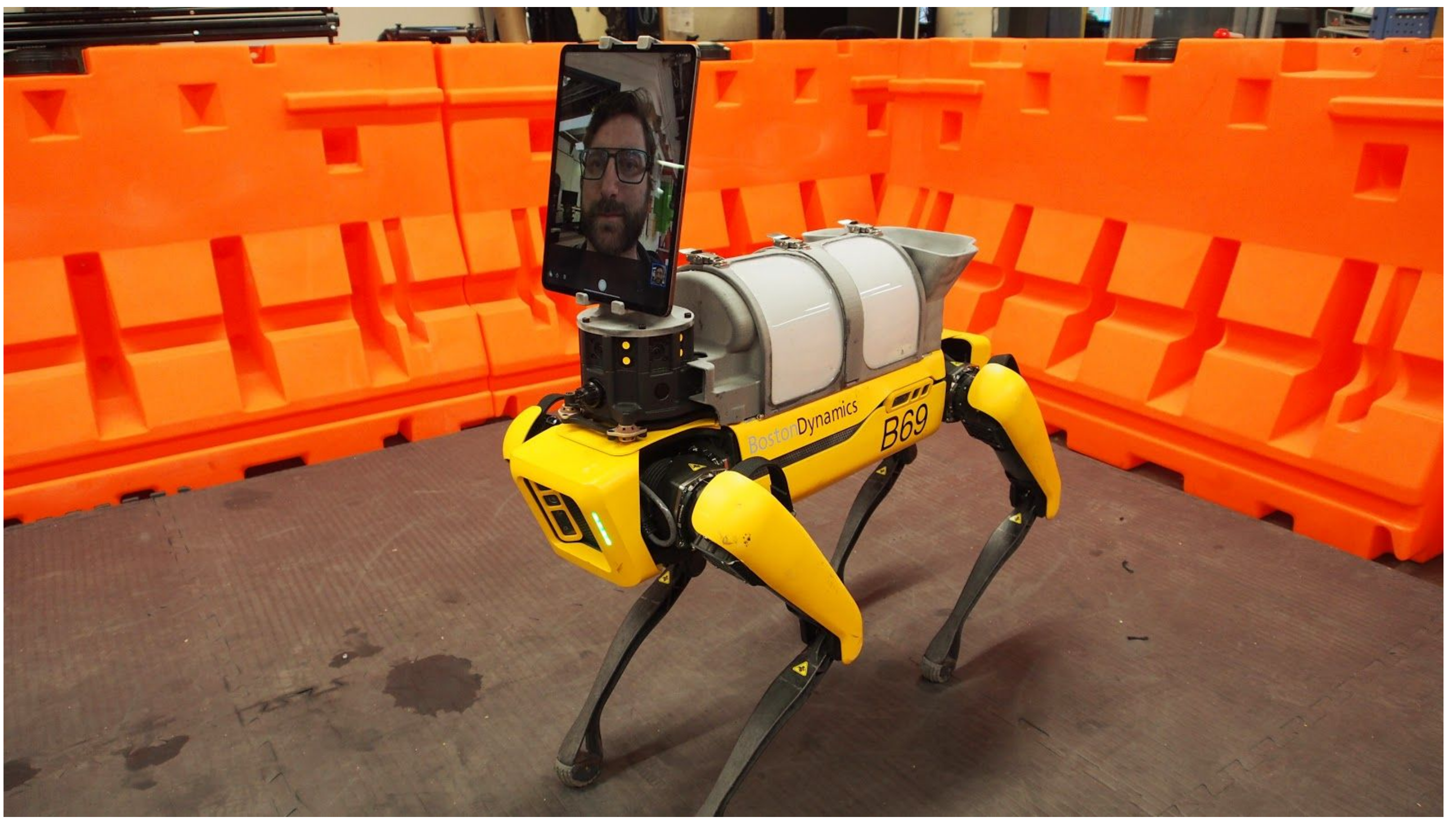
- See the Remote vitals inspection section, below

## Current status: Deployed

Boston Dynamics created a universal tablet mount that facilitates video conferencing with patients in portrait or landscape mode. Any LTE-enabled tablet that meets hospitals' information security guidelines can be used here. Healthcare providers initiate a Skype or Facetime session between a mobile device and the tablet to conduct patient interviews.

Robot control is accomplished using mesh radios between the operator tablet and the Spot robot. The operator tablet displays a spherical camera image to provide situational awareness around the robot and enables the operator to drive the robot between patients' rooms.

The tablet and radio mounts have smooth surfaces and all wiring is covered, facilitating disinfection with Clorox wipes or soapy water.




## Resources

These solid models are available for download in this Github repository:

- **Robot tablet mount**

- Robot radio mount
- Radio cover

# Remote vitals inspection

Allow healthcare providers to conduct triage and patient rounds while minimizing their potential exposure to COVID-19 and reducing PPE consumption. Gather basic health data. Enable remote or quarantined healthcare workers to support on-the-ground staff.

## Solution requirements

The robot should be able to measure:

- Body temperature
- Respiratory rate
- Pulse rate
- Oxygen saturation and blood pressure

Additionally, the robot should be able to read instruments connected to patients.

## Current status: Prototype

### Body temperature

Boston Dynamics has prototyped a system that uses an IR camera to measure body temperature. The temperature is measured at the patient's tear duct against a thermal reference in the image.

### Respiratory rate

Assuming the patient is wearing a mask, the same IR camera image is used to detect exhaled air on the mask to calculate respiration rate in breaths per minute.

### Pulse rate

Boston Dynamics is investigating multiple ways to detect heart rate. One method evaluated utilizes an RGB camera data to capture changes in blood vessel contraction to calculate heart rate. The patient's face must be well-lit, stationary, and not blocked by any objects. Unfortunately, with this method, accuracy decreases as heart rate increases. See Photoplethysmography (PPG) later in this document for more information.

### Oxygen saturation and blood pressure

We do not currently have deployable solutions to measure oxygen saturation or blood pressure robotically. The basket mounted on the robot could deliver a pulse oximeter for self-administration. The robot operator could view the resulting data from the oximeter on video.

### Resources

We've considered these sensors, however have not tested all of them. Note that some are contact-based, which have challenges in robotic and COVID-specific applications.

Oxygen Saturation

- Maxim Devices Pulse Oximeter Evaluation Board for developing a more integrated solution
- Nonin USB Pulse Oximeter for use with a computer like SpotCORE

Blood Pressure

- Omron Wireless Blood Pressure Monitor could be integrated with a smartphone
- Wrist Blood Pressure Monitor with USB for use with a computer like SpotCORE

Refer to the Photoplethysmography (PPG) section later in this paper

# Disinfecting hospital rooms

Provide a means for effective and efficient patient room disinfection after each patient interaction. The mobile robot disinfects patient rooms using UV-C light, which kills virus particles, but cannot be used around people. Alternatively, the robot could be used as a platform for teleoperated or autonomous chemical disinfection.

## Solution requirements

1. Deliver an effective dose to key surfaces in reasonable time.

2. Safety — Designed to turn off UV-C radiation or chemical spray when the operator or patient is expected to be nearby. Glass light bulbs, if used, are mounted in a way to reduce the risk of shattering in case of collision.

## Current status: Design

- Competing UV-C technologies take 20-30 minutes to clean a typical hospital room and deliver 6-10 times more irradiance ($W/m^2$) than Spot payload power (~300W limit) can deliver in a reasonable amount of time (> 1500W prime power).
- Due to these power limits, disinfecting an exam room with UV-C would take 30-60 minutes with Spot vs. 5-10 minutes using competing technologies. Additional onboard power sources, or more efficient UV-C radiation sources, could reduce this time.

## Resources

- Disinfection, Sterilization, and Control of Hospital Waste in Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases (Eighth Edition) on sciencedirect.com
- UVD Disinfection Robot on uvd-robots.com
- IEEE Spectrum: Autonomous Robots Are Helping Kill Coronavirus in Hospitals
- Clorox Healthcare Optimum-UV Enlight® System
- Clorox Healthcare Optimum-UV® System product sheet (PDF)

# Disinfection of mobile robots

Allow healthcare workers who remotely operate robots in potentially infectious areas to effectively disinfect robots after use. An enclosed UV-C station could be used to irradiate and disinfect the robot.

## Solution requirements

1. Deliver an effective dose to all key robot surfaces within a reasonable time window.

2. Sufficient disinfection of robot surface — will need a way to quantify what level is sufficient (i.e., which surfaces are most critical, how much % reduction, etc.)

3. Safety — Designed to turn off UV-C radiation when the operator or a patient is expected to be nearby. Glass light bulbs are mounted in a way to reduce the risk of shattering in case of collision.

## Current status: Design

Plenty of power available from a wall plug. Mount some (10x OSRAM 21283 G55T8/OF 36in 55w G13 T8 Germicidal Tube or similar) UV tubes in a tent, have Spot stand for 5 minutes, sit for 5 minutes for good exposure on legs. Adjust exposure based on measured irradiance, assuming 0.5-1 meter distance from lamps to Spot. Requires pre-cleaning of Spot to remove macroscopic soiling. Test material compatibility under high levels of UV-C exposure.

# Internal delivery

Leverage the robot's autonomous and semi-autonomous capability to deliver food, medicine, and other supplies to patients in isolation, minimizing health worker exposure, and PPE consumption.

## Solution requirements

- Tray for carrying most common supplies.
- Optional load securement or locking mechanism.

## Current status: Prototype

Boston Dynamics has prototyped a 3D-printable tray for carrying small supplies (such as a mask for the patient).

## Resources

These solid models are available for download in this Github repository:

- Robot tablet mount
- Robot radio mount
- Radio cover

# Photoplethysmography (PPG)

Photoplethysmography (PPG) is a technique of detecting heart rate by analyzing the reflected light off a person's skin. It operates on the principle that the constriction and dilation of capillaries in the skin causes different amounts of absorption of incident light. Wrist-mounted health trackers often use PPG to detect heart rate, taking advantage of the close-contact between the device and the skin.

Remote PPG (RPPG) applies PPG at a distance, and usually includes other techniques such as face-tracking to enable non-contact heart rate monitoring.

The general steps are:

1. Detect a face.

2. Pixel selection (top ⅔ of subject face becomes region of interest, or ROI).
3. Signal extraction (average RGB value of each pixel in the ROI taken over time).
4. Filter out noise (like head movement).
5. Detect peaks in the signal from the ROI, identify these as beats.
6. Calculate heart rate from these peaks.

RPPG accuracy decreases with increasing heart rate, increasing head movements, overexposed portions of the subject's face, lower camera resolution, and lower frame rate.

## References


- noldus.com: Behavioral Research blog: What is RPPG?
- NeuroData Lab on medium.com: Every beat counts. Comparing Remote Webcam Heart Rate Detector to Wearables